Is it a MUST to add Upstream Devices for High GVF Multiphase?

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Objective

High accuracies in measurement of the gross liquid and net oil flow rates at high GVF levels in the multiphase flow is identified as one of the most demanding needs of the industry, especially in high watercut environments. The underlying factor that decides the accuracy of the net oil flow rate measurement is the accuracy at which the gross liquid & watercut are measured and the prevailing watercut in the flow. It is an established fact that accuracies falter with increasing GVF in the multiphase flow.

The purpose of this paper is to present the performance results of a newly developed Compact High GVF Haimo multiphase meter that addresses the above needs,

- without having to use an Upstream Separation Device for high GVF application
- while retaining the accuracies within ±2% absolute for watercut and 10% relative for liquid and gas flow rates at 90% confidence level.
- while also optimising the footprint, the cost, the weight of the solution

Further developmental work and trials are in progress to achieve the targeted accuracy levels under very high GVF conditions as well.

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1.0 Definitions

1.1 GVF – Gas Volume fraction

The gas volume flow rate, relative to the multiphase volume flow rate, at the pressure and temperature prevailing in that section. The GVF is normally expressed as a fraction or percentage.

1.2 WC – Watercut

The water volume flow rate, relative to the total liquid volume flow rate (oil and water), both converted to volumes at standard pressure and temperature. The WC is normally expressed as a percentage.

1.3 Moderate GVF (25-85%)

The Moderate GVF can be considered as the 'sweet spot' of multiphase meters, i.e. the range where they have their optimum performance, and where at the same time traditional single-phase meters are not a viable option.

1.4 High GVF (85-95%)

Entering this High GVF range the uncertainty of multiphase meters will start to increase, with a rapid increase towards the upper end of the range. This increase in uncertainty is not only linked to more complex flow patterns at high gas fraction, but also because the measurement uncertainty will increase as the relative proportion of the fraction of the component of highest value (in this case the oil) decreases. In some cases partial separation is used to move the GVF back into the Moderate GVF range.

1.5 Very high GVF (95-100%)

This upper end of the multiphase range could also be termed the ‘wet gas’ range. In the lower end of the very high GVF range the measurement performance of in-line multiphase meters may still be sufficient for well testing, production optimisation and flow assurance. For allocation metering, in particular at the high end of this range, often gas is the main ‘value’ component, and a wet gas meter would be the preferred option.

This corresponds to a Lockhart-Martinelli (LM) value in the range from 0 to approximately 0.3.

1.5 Measuring envelope

The area's in the two-phase flow map and the composition map in which the MPFM performs according to its specifications (elaborated in 1.6)

1.6 Accuracy Specifications

The term “accuracy specifications” in this paper shall refer to carrying out measurements within ±2% abs. for watercut and 10% relative for liquid and gas at 90% confidence level. All data points within any of the Measuring envelopes presented in this Paper are consistently measured within the Accuracy Specifications.

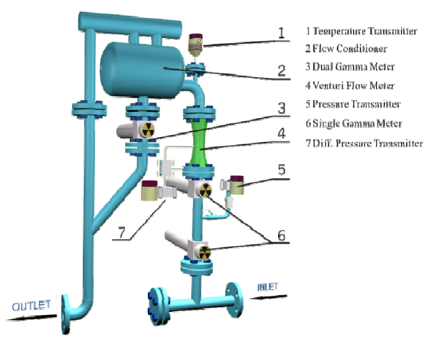
Reader’s special remembrance to the above definition is requested while the above term is read in this Paper in different contexts.

2.0 MFM 2000 + Upstream Separation Device (*Accuracy Specifications* applicable upto 99.8% GVF)

MFM 2000 - the basic configuration of the Haimo multiphase meter is a combination of a gas / liquid two phase (inline) and a full range three phase water cut meter. The watercut measurements are carried out independent of the gas / liquid flow rate measurement.

The gas / liquid two phase meter consists of a venturi and one single gamma (59.5 keV) sensor. The three phase water cut meter comprises a dual energy (22 and 59.5 keV) gamma sensor and a flow conditioner located upstream. Measurement of the gas and liquid streams is carried out upstream of the flow conditioner in the two-phase flow meter.

The Dual gamma meter measures the water cut under a stable flow regime, which is critical for the water cut measurement accuracy. Net oil flow rate is finally calculated based on the gross liquid and water cut measurements.



Schematic of Enhanced MFM2000 Series Multiphase Flow Meter

***“Accuracy specifications”* applicable upto 90% GVF**

The combination of the flow conditioner and the dual energy gamma absorption watercut meter helps Haimo achieve the +/-2% abs. error on watercut over 0-90% GVF range with a 90% confidence level

It is a well established fact that the accuracies in measurement of watercut and liquid / gas flow rates fall with increasing GVF. An upstream gas conditioning device is integrated upstream of the MFM 2000 series meters to extend the GVF to 99%)

With an Upstream Separation Device

***"Accuracy specifications"* applicable upto 99.8% GVF**

The gas conditioning unit is used to absorb shock in flow rate of the incoming multiphase flow such as severe slugging, and to separate the multiphase flow initially. The gas conditioning units separates the liquid drops from the flow to ensure no liquid is diverted into the gas leg. The gas leg is fitted with a control valve and vortex meter.

Based on the GVF measurements from the MFM initially when the control valve is fully closed, the control valve mounted on the gas leg regulates its opening to control the gas flow rate through the same leg thus controlling the GVF level in the multiphase leg; the vortex flow meter measures the wet gas flow rate through the gas leg. Sections hereunder detail the measurement philosophy and principles behind the Haimo technology

2.1 The technology within …

Haimo targets a narrow band of accuracies specified in Section 1.6 of this Paper as the Design Basis. Increasing levels of GVF in the incoming multiphase flow affect the measurement of the phase flow rates and phase fractions.

The objective of the design is to maintain these accuracies consistent over all the points falling within the *Measurement envelope* of the meter. It is to be remembered that the accuracy with which the watercut is measured impacts the accuracy of the net oil flow rate, and it is pronounced at high watercut conditions.

The fundamental philosophies and principles behind the same are listed hereunder:

2.1.1 Measurement Philosophy

<u>Separation of Phase flow rate and Phase fraction measurements</u>

Water cut measurement errors are pronounced when the GVF levels are high and/or severe slugging conditions prevail in the flow. Incoming multiphase flow may exhibit one or more combinations of "high GVF" or "slugs" or "high watercut".

Measurement of the total flow rate and Gas Void Fractions are well established using the principles of Venturi and Gamma absorption, and follow a predictable and acceptable accuracy under very high GVF conditions. The effect of increasing GVF or slugging in the multiphase flow is more severe in affecting the WLR measurement accuracy.

The solution to measure WLR accurately is to introduce an independent section made up of "a flow conditioner and a low Dual energy gamma absorption watercut meter" with suitable conditioning done to the multiphase flow during the watercut measurement

Conditioning upstream of the 3 phase watercut measurement

The net oil flow rate from a well is a "calculated" figure from "two measurements" taken by the multiphase meters namely "Water Liquid Ratio" and "Gross Liquid Flow Rate". With higher water cuts coupled with higher uncertainties of water cut measurement, the net oil flow rate inaccuracy worsens.

Haimo's watercut meter is installed downstream of the built-in flow conditioner that conditions the flow, mitigates slugs and reduces the GVF level to the watercut meter. This helps the watercut measurement errors within +/- 2% abs. for the full range of stated GVF in the meter's *Measurement envelope.*

The accuracy of watercut measurement in various comparison tests establishes that the WLR in the multiphase flow outlet to the flow conditioner is same as that of the incoming multiphase flow, but at depleted gas conditions.

2.1.2 Measurement Principle

Low energy gamma absorption technology

Haimo meters utilise the photo electric effect that is associated with the low energy gamma sources, in this case, Americium 241 (Am 241). Am 241 emits alpha and gamma rays. Gamma rays are emitted at 59.5 KeV energy level. A silver foil is used to generate X rays at an additional energy level of 22 KeV.

The photo electric effect mass attenuation coefficient is

- directly proportional to the 4^{th} to 4.8^{th} power of Z – the atomic number of the interacting matter
- and inversely proportional to the 3^{rd} power of the energy level of the gamma source used

Phase fractions are determined by exposing the multiphase flow to two different energy levels of gamma rays 59.5 and 22 KeV. By solving the 2 independent equations generated from exposure to the two different energy levels and the continuity equation, the phase fractions are calculated.

Under this measurement principle, the phase discrimination occurs by measuring the relative presence of the Carbon to Oxygen atoms in the Oil and water respectively. This gives the Haimo technology the unique advantage of measuring oil and water fractions, even if separated by a narrow margin of density.

3.0 Haimo's experience with Upstream Separation Devices

3.1 Installation references

Haimo been offering skid configurations with Upstream Separation Devices from the year 1999. Over 100 of these units that have been supplied are high to very high GVF configurations fitted with Upstream Separation Devices. These units function up to a GVF of 90% without having to use the upstream units and for GVF's above the cut-off value of 90%, the upstream unit comes into play along with its combination of cyclone, control valve and the vortex meter. Skids rated up to 900#, made out of Incolloy and Hastelloy internals for cyclones and for vortex meters and control valves are in operation worldwide.

The presence of the flow conditioner in the skids also helps to allow for a higher GVF handing capacity before the partial separation unit comes into play.

The use of the upstream gas conditioning unit has also proven to be resulting in weight, volume and costs and delivery as commercial disadvantage issues to Haimo and the customers.

The performance of such configurations are well established with various third party live crude FAT reports and field studies.

MFM 2000 series meters with and without Upstream Separation Device

SPE 84505 Multiphase flow meters: Experience and Assessment in PDO co-authored by Busiadi, Khamis, and Bhaskaran, Haridas, Petroleum Development Oman (PDO),Oman, presented at the SPE Annual Conference and Technical Exhibition, Denver, Colorado, 5-8th October 2003 shares more details of the third party testing carried out on such a configuration.

The typical challenges to be addressed while using the upstream devices can be listed as follows:

- Material selection issues
- Footprint, weight and volume.
- Cost and economics

3.2 Material selection and costs associated with Upstream Separation Devices

Exotics

High chlorides and sulphides in the flow may require the use of exotic materials such as Duplex stainless steel, Incolloy, Hastelloy etc. Designing of the process vessel with such materials prove to be expensive, not only from the cost of the raw materials, but also the special fabrication standards and procedures to be followed. Procurement of exotic material – for vessel internals, control valves and vortex meters can also be very expensive impacting on the cost effectiveness of the solution provided

Fabrication

High pressure High GVF skids to be fitted with upstream devices would warrant special standards and skills to be followed for fabrication.

Foot prints, weight and volume

When appropriately designed to handle the required liquid turndown, GVF and slugs, the multiphase meter with an Upstream Separation Device assembly when installed in field should raise a few interesting questions.

For fixed onshore applications, it is possible that footprints and the height are not a major constraint. However, when such a units are to be transported from one well head to another for mobile well testing services, the portability and compactness advantages may be lost.

For offshore applications, it shall be virtually impossible to even move such a unit onto the platform where space is premium. Additional weight caused by the upstream units also poses challenges for easy mobility between platforms, while also impacting the efficiency of the platform in terms of structural design and utilisation.

Costs and delivery

The above can result in considerable costs for the completed units with half of it accounted from the Upstream Separation Device with associated control valve, vortex meter and piping. Longer delivery periods owing to the use of exotic materials and special fabrication needs may not be acceptable to customers looking for quick solutions.

4.0 Motivation to develop the Compact meter solution

Given the above backgrounds and with an effort to develop a balanced solution between "accuracies" and "cost-effectiveness", Haimo embarked on a special project to develop a new meter to extend the *Measuring envelope* of the Haimo MFM 2000 series multiphase meter to *High GVF* conditions without having to use Upstream Separation Devices.

It shall be noted and reinforced here that efforts taken by Haimo are to be within the *"Accuracy specifications"*. The new term "Compact High GVF meter" is used henceforth in this paper.

Partial list of challenges addressed in this new development:

- Wide liquid turndown requirements with associated gas flow rates
- Suitable slip models for Phase flow rate measurement
- Liquid and gas handling capability of the flow conditioner for a wide turndown of liquid and gas
- Sample assurance to the watercut meter downstream of the flow conditioners under gas depleted flow condition for all points falling within the *Measuring envelope* of the meter

The paper shall present the results achieved from the modifications carried out in the skid, rather than focussing on the details of the modification.

In Section 6.0, the results of testing in a third party facility are shared. The testing was carried out on the first prototype design of the Compact high GVF meter in March 2004.

The test was witnessed by a Global Service company offering Field surveillance services and mobile well testing services. The test was carried out in the DOD facility described in Section 6.0

5.0 Description of the Compact solution

5.1 Description of meter tested

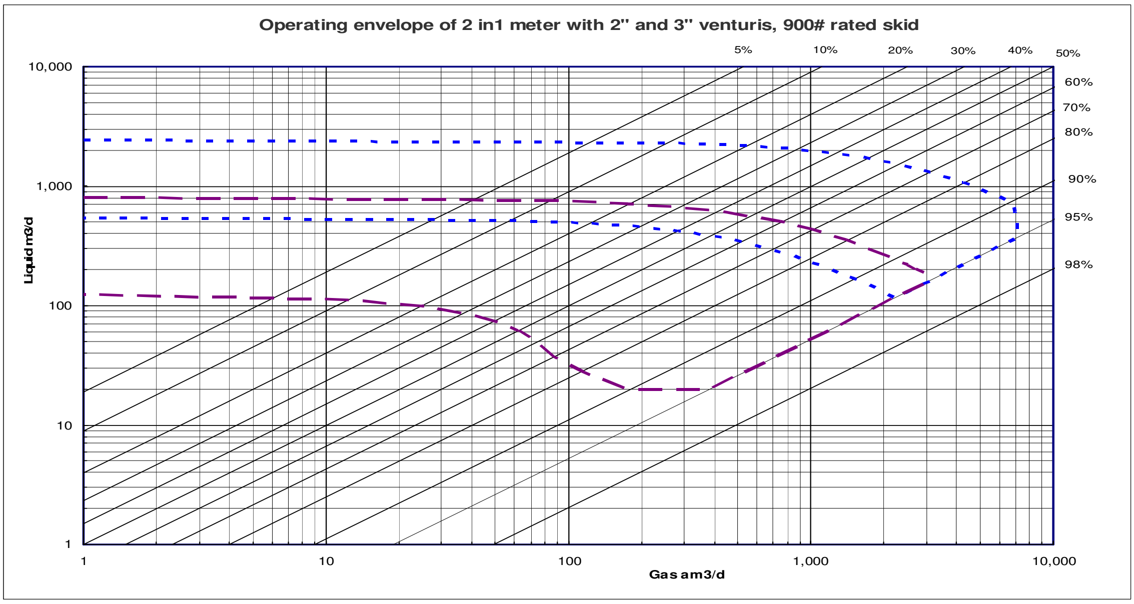
The meter tested in the third party facility is a 2 in 1 meter configuration, built with a 3" and 2" venturis, which are valved in such a way to be in series or have only one on-line.

The two sizes of venturis bring a wide Measurement envelope to measure liquid from as low as 20 m3/d (125 bpd) to 2,400 m3/d (8,792 bpd), with corresponding high GVF conditions, better interpreted from the *Measurement envelope* presented hereunder.

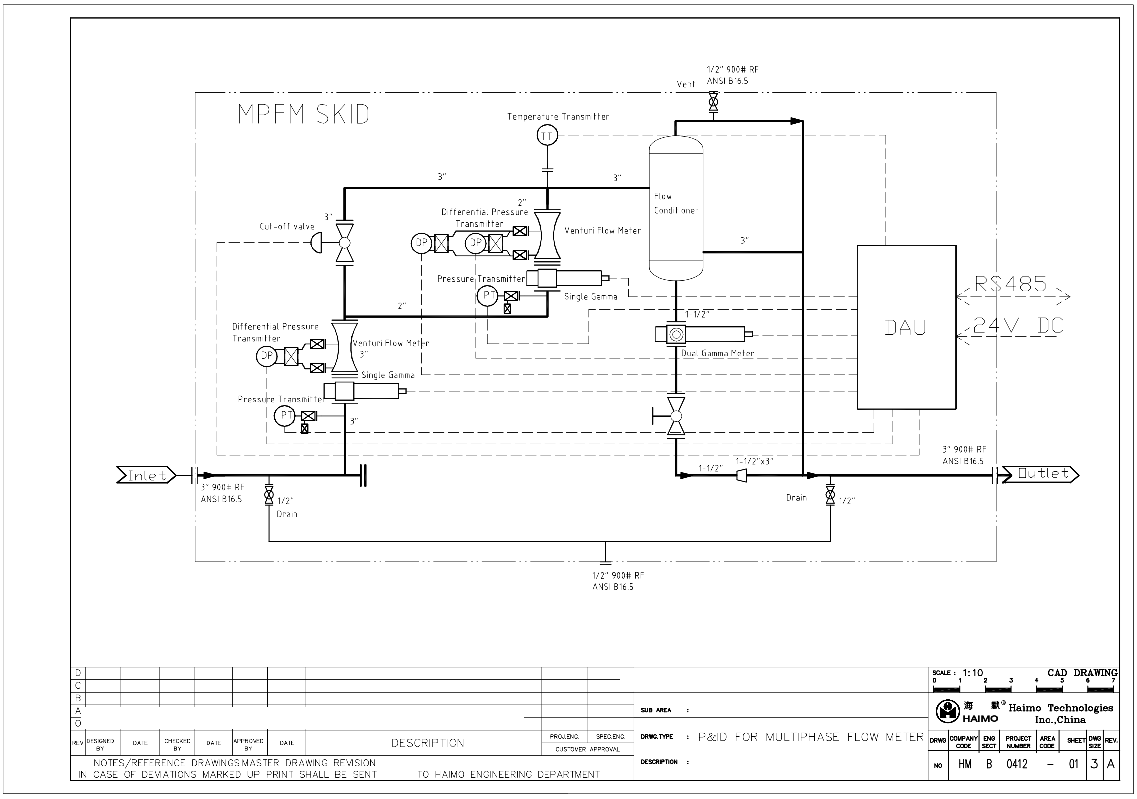
A wide turn down meter is chosen to address requirements of customers with large turndown requirements, and limited pressure drop allowance, while also to test the turndown capability of the flow conditioner upstream of the watercut meter.

5.2 *Measuring envelope* of the meter in a 2 phase flow map

(GVF limit set from test points that met with the *Accuracy Specifications,* post testing)



5.3 P&ID of the meter tested



5.4 Picture of the skid during the Third party testing

5.5 Operating Principle

The meter consists of two venturis with in-built single gamma meters installed respectively on two multiphase legs, a flow conditioner and a Dual gamma meter. The phase fractions and flow rates are calculated based on the following measurements:

- Total flow rate of the multiphase fluids (TFR) is measured by the two Venturi tubes. (Lower flow rate is measured by 2" Venturi and higher flow rate is measured by 3" Venturi). The single gamma meter gives an additional input of density for the venturi calculations.

- The cut off valve directs the flow through both the venturis in case of low flow rates, while measurements are just captured from the smaller venturi for flow computations; for higher flow rates, the fluids are routed through the larger venturi alone in this unique valving arrangement

- Single gamma meter also measures the ratio of gas flow to the total flow rate at line conditions (Gas Void Fraction)

- The water Liquid Ratio (WLR) is measured by a Dual gamma meter; the WLR measurement is carried out downstream of the improved flow conditioner. This new vertical flow conditioner has five functions:

    - to buffer the slugs
    - to deplete gas in the outlet to the Dual gamma meter
    - to replenish the Dual gamma meter with fresh samples
    - to provide a homogenised multiphase fluid to the Dual Gamma meter
    - to extract liquid in the gas depleted multiphase that is representative of the WLR of the incoming multiphase flow to the meter inlet.

    In short, the new flow conditioner is a combined device consisting of separation, mixing, conditioning and sampling elements.

- The actual Gas flow rate is calculated as a product of TFR x GVF (calculated from Gas Void fraction)

- The Gross liquid flowrate (GFR) is calculated as a product of TFR x (1-GVF)

- The Water flowrate is calculated as a product of GFR x WLR and the Oil flowrate is a product of GFR x (1-WLR)
- Pressure and Temperature transmitters are mounted in appropriate locations in the skid for correction of measured values to standard conditions and for applying to EOS and/or PVT corrections

5.6 Claimed accuracies of the meter

The Compact meter is set to achieve the *Accuracy specifications* over the *measuring range* of the meter. The typical accuracies expected out of the meter skid are as follows, to be confirmed during the testing in the Third party facility:

***Accuracy Specifications* / Uncertainties :**

Gross liq.flow rate:	+/- 5% relative (GVF<50%)
	+/-10% relative (GVF>50%)
Watercut:	+/- 2 % absolute
Gas flow rate:	+/- 10% relative

Uncertainties are based on 90% confidence level

Repeatability

Gross liq. flow rate:	+/- 2.5% relative (for GVF<50%)
	+/- 5% relative (for GVF>50%)
Watercut:	+/- 1 % absolute
Gas flow rate:	+/- 5% relative

6.0 Performance testing of the meter in the third party facility

6.1 Description of DOD Facility and test procedure

The DOD Multiphase Flow Facility is located in Daqing Oilfield, Daqing City, China. The facility was conceptually designed by National Engineering laboratory (NEL), Glasgow, UK. The test facility is located in the middle of the Daqing oil field, and provides live crude oil, produced water and natural gas for the testing. The tests carried out in the DOD shall be considered as a SAT (Site Acceptance test) as the meter is calibrated with the fluid samples in the field.

It is approved by China National Measurement Institute and China National Petroleum Corporation (CNPC) and by PDO – Oman, and frequently used by Shell, Conoco Phillips among other international operators.

The specifications of the DOD facility are presented in Annexure 1:

6.2 Selection of Test points

The objective of the test was to establish the extent to which the GVF limit of the *Measuring envelope* could be stretched while also meeting with the *Accuracy Specifications*.

The tests were carried out independently for the 2” and the 3” measurement legs for different flow rate ranges. A total of 100 test points were selected to cover testing upto high GVF conditions to evaluate the meter performance from minimum to maximum liquid flow rates, while also varying the watercuts from 0-100%.

While the objective is to establish the meter performance in the high GVF environment, emphasis was placed on maximising the test points at above 80% GVF

For the 2" leg,out of 50 test points:

27 test points were above 80% GVF
17 test points were above 90% GVF
6 test points were above 95% GVF, upto 96.1%

For the 3" leg, out of 50 test points:

31 test points were above 80% GVF
20 test points were above 90% GVF
5 test points were above 95% GVF upto 95.4%

In summary, out of 100 test points, 37 were above the 90% GVF range.

Repeatability tests were carried out on 5 test points each for the 2" and 3" measurement legs

6.3 Test results

The test results are presented for the different measurement sections, separately and combined based on the following graphical charts presented elsewhere in the paper:

- △ Liquid flow rate Vs Gross liquid
- △ Watercut Vs Gross liquid
- △ Gas Vs Gross liquid
- △ Liquid Vs GVF
- △ Watercut Vs GVF

Detailed test results are presented in Annexure 2

6.4 Analysis of test results

Watercut ABSOLUTE errors:

- The targeted criteria was found to be bettered in the absolute error on watercut plotted against GVF; At 90% confidence level, the watercut was measured within 1.8% for the 2" leg and 1.3% for the 3" leg; both legs combined, the watercut absolute error at 90% confidence level was established to be within 1.8% - better than the targeted criteria of 2% absolute at 90% confidence level

- Abs. errors on the watercut was found falling within 1.8% and 1.5% at 90% confidence level respectively for the 2" and 3" legs; the combined test results when plotted against the Gross liquid showed an absolute error of 1.8% at 90% confidence level

- No charts have been drawn or highlighted for watercut errors against the watercut itself, as the watercut measurement based on dual energy gamma absorption principle is well established to be independent of water continuous and oil continuous flow regimes.

Liquid flow rate RELATIVE errors:

- At GVF below 50%, as expected, the 2" and 3" legs produced liquid flow rates relative errors that were within 5.7% and 1.9% respectively at 90% confidence level; the combined results were within 3.2%.

- Over the 50-95% GVF range, the 2" and 3" legs produced liquid flow rate relative errors that were within 7.3% and 5.6% respectively at 90% confidence level; the combined results were within 6.8%.

Gas flow rate RELATIVE errors:

Relative errors on gas flow rates were plotted against various liquid flow rates.

- At 90% confidence level, the gas flow rate errors were within 11% and 9.8% for the 2" and 3" legs respectively;
- The combined gas errors were within 10.4% relative at 90% confidence level

Repeatability test results were well within the claimed Repeatability figures

7.0 Conclusions and Benefits

- The objective of working out a new solution for high GVF without having to use a Upstream Separation Device seem to have been achieved with excellent test results;

- The new configuration of Compact High GVF meter successfully met and exceeded its Acceptance criteria. The main objective was to asses its performance, confirm the quality of the measurements and check its compliance with the *Accuracy specifications.*

- The consistency of the absolute error on watercut MUCH LOWER THAN 2% for the full range of the GVF and liquid flow rates re-establishes the independence of the watercut measurement technology over the GVF and liquid flow rates, now for high GVF

- The accuracy results obtained for gas flow, gross liquid flow and water liquid ratio measurements demonstrate the following:

    - efficiency of the flow conditioner technology and its great advantage of measuring the water liquid ratio (WLR) independently of the Gas volume fraction (GVF)

    - capability of the flow conditioner to handle the wide turndown of the liquid from the 2 in 1 meter

    - capability of the flow conditioner to handle high GVF without compromising on the efficiency to mitigate slugs, deplete gas and provide a representative sample of multiphase fluid with WLR same as that of the incoming multiphase flow

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ANNEXURE 1 - DESCRIPTION OF THE DOD FACILITY

The multiphase pipeline size is DN50,80, 100
The operating pressure is 200 – 500 KPa.
The Max. fluid temperature is 80 C.

The test fluids used in DOD are as follows:

Oil phase - Crude oil (water in oil less than 0.5%) from Daging Oilfield
Gas phase - Natural gas (liquid in gas less than 0.5%) from Daging Oilfield
Water phase - Produced water (oil in water less than 0.5%) from Daging Oilfield

The capacity of the DOD facility is given below:-

Max. Oil flow rates:	1,200 m3/d
Max. Water flow rates:	1,200 m3/d
Max. Liquid flow rates:	1,200 m3/d
Max. Gas flow rates:	28,080 Sm3/d

The accuracy of the DOD facility is given below:-

Oil phase:	+/- 1.0 % relative (PD meter)
Gas phase:	+/- 1.5 % relative (Turbine meter)
Water phase:	+/- 1.0 % relative (Turbine meter)

The repeatability of the DOD facility is given below:-

Oil phase:	+/- 1.0 % relative
Gas phase:	+/- 5.0 % relative
Water phase:	+/- 1.0 % relative

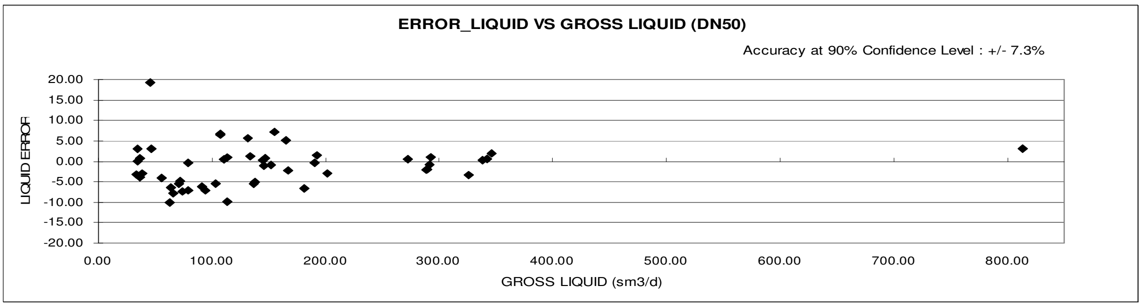
The range-ability of the DOD facility is given below:-

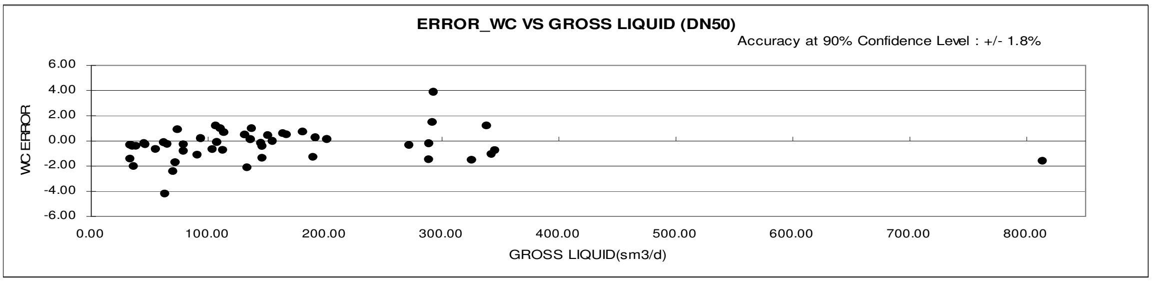
GVF:	0 - 100 %
Water cut:	0 - 100 %

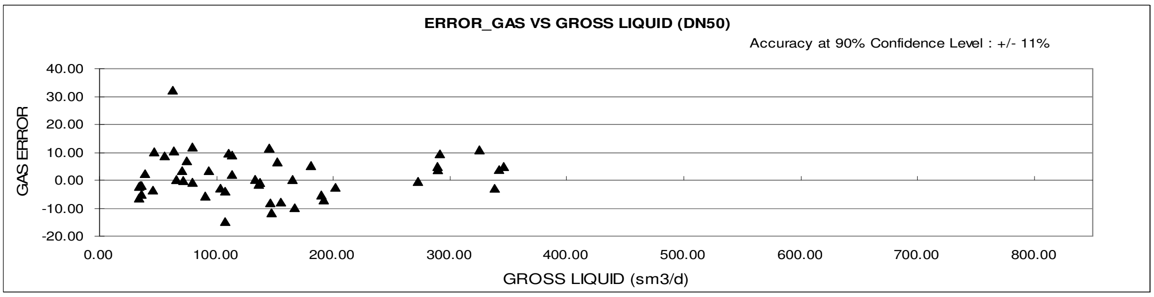
The MFM skid is be mounted on the multiphase flow testing pipe section of DOD's facility. The multiphase piping is downstream of the mixing point of the reference single-phase flow meters for oil, gas, and water individual phases. The oil, gas, and water single phase flows shall be first metered by the reference single-phase flow meters respectively.

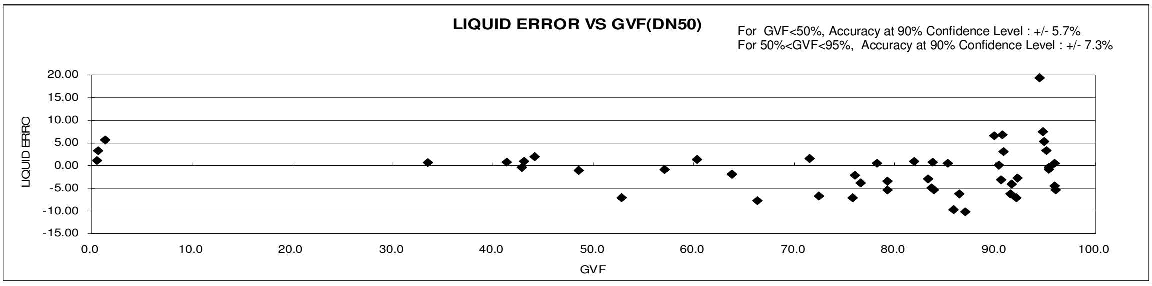
DOD's own reference temperature and pressure transmitters are located close to the MFM skid. The DOD's reference values of gas flow rate are calculated according to the temperature and pressure reported by the DOD transmitters. This way the inlet single-phase flow rates measured by the reference flow meters could be compared with the flow rates of multiphase flow measured by the MFM skid.

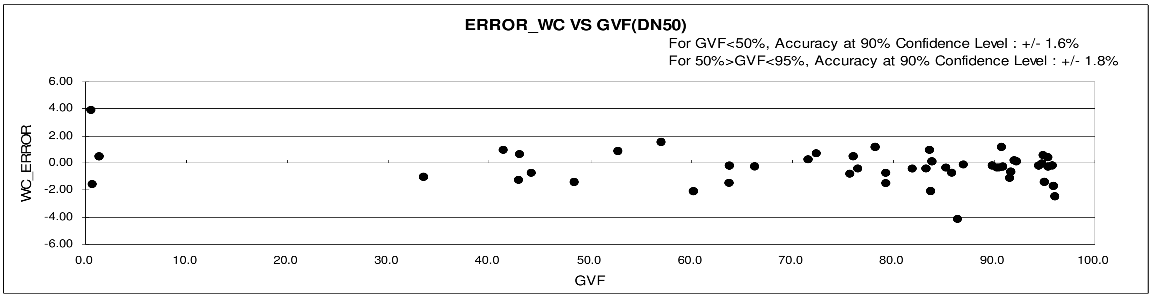
ANNEXURE 2 - TEST RESULTS
PERFORMANCE RESULTS FROM THE 2" LEG



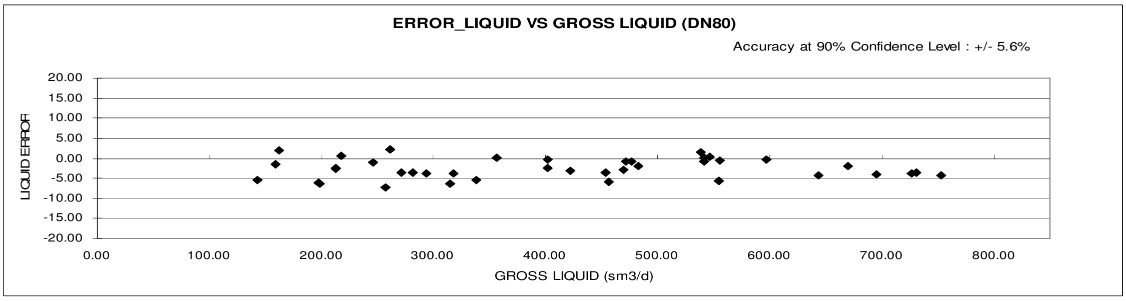


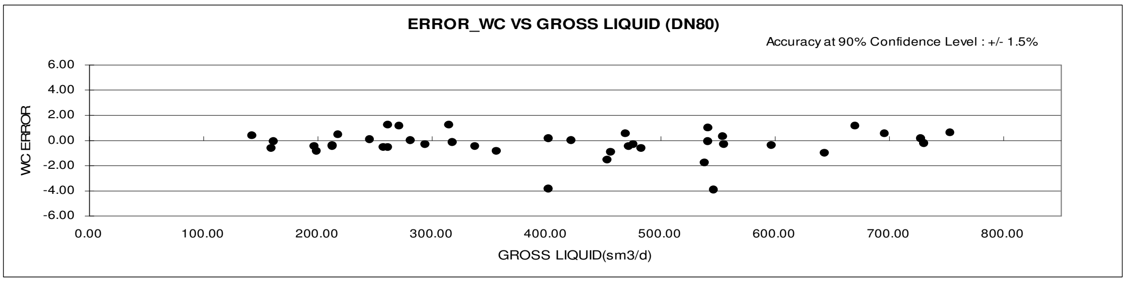


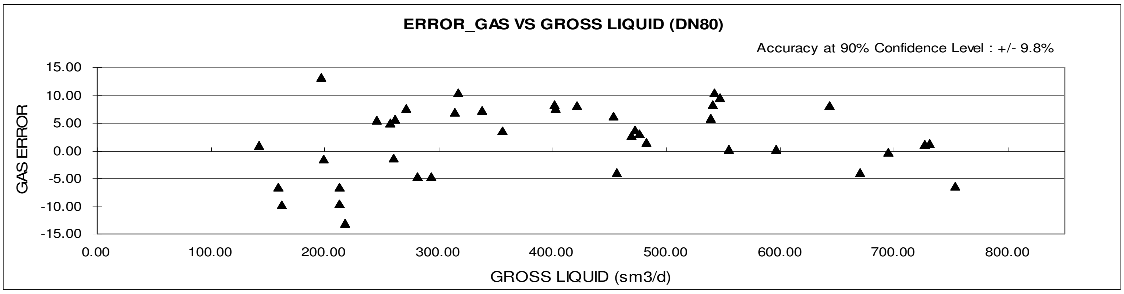


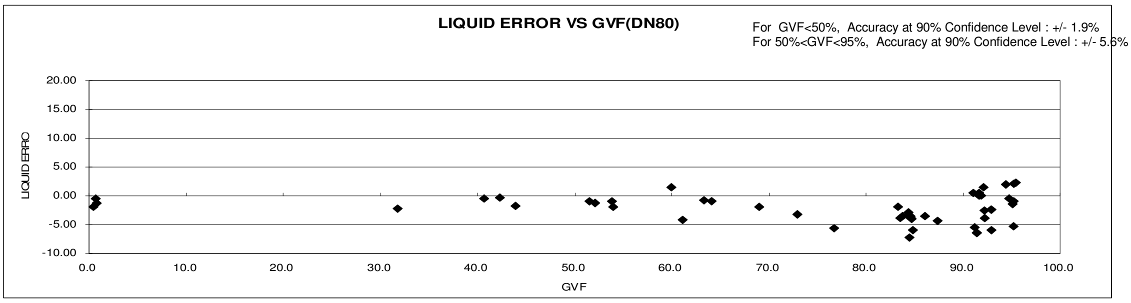


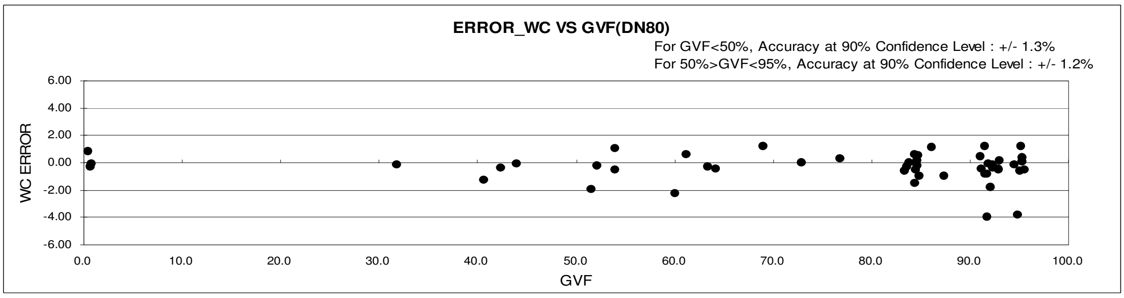
PERFORMANCE RESULTS FROM THE 3" LEG











COMBINED RESULTS FROM THE PERFORMANCE OF THE 2" AND 3"LEGS